PATENT SPECIFICATION

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COMPLETE SPECIFICATION.

Improvements in or relating to Apparatus for the Measurement and Integration of Fluid-Velocities.

I, WILLIAM GEORGE BIRD, a British Subject, of 11 Cranbrook Road, Redland, Bristol 6, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention concerns improvements in or relating to apparatus for the measurement and integration of fluid-velocities and more particularly relates to devices for the measurement of the relative velocity between a body and a contiguous fluid or of the total flow of the fluid past the body in a specified time. Such devices are applicable for use as anemometers, as ship's logs or leeway-indicators, and as air-speed indicators or air-distance indicators for aircraft, or alternatively as flow-meters to measure the velocity of flow of a fluid through a pipe or channel and/or to measure the total quantity of fluid passing a given point in the pipe or channel in a specified time, or for any other similar application.

There are three systems in general use at the present time for measuring the relative velocity between a body and a contiguous fluid. In one of these systems, an impeller or rotor is rotatably pivoted on the body, or on a part fixed relatively to the body, and is immersed in the fluid, said impeller or rotor having either, as for example is the case in a windmill, inclined blades radial to its axis of rotation with the latter arranged substantially along the direction of flow of the fluid relative to the body, or, as is the case in the well-known Robinson anemometer, cups or the like on arms radial to the axis of rotation with the latter arranged substantially at right-angles to the direction of flow of the fluid relative to the body. Flow of the fluid relative to the body causes the impeller or rotor to rotate with an angular velocity dependent on the relative velocity between the body and the fluid and this rotation may operate, by electrical or mechanical means, an indicator which is suitably calibrated to indicate the said relative velocity.

Such arrangements using an impeller or rotor suffer in many applications from the disadvantage that the angular velocity of the impeller or rotor is not as it is desirable that it should be, accurately proportional to the relative velocity between the fluid and the body and independent of the density of the fluid unless the impeller or rotor can rotate completely freely without frictional or other constraint, and such a completely free rotation is obviously very difficult to achieve and maintain in practice. Furthermore, the resistance to the flow of the fluid of the impeller or rotor with its mounting may be considerable, and in some applications, such as in high-speed aircraft for example, may be very objectionable for this reason.

In the second system, a so-called Pitot-static head is fixed on the body, or on a part fixed relatively thereto, and is immersed in the fluid, the difference between the dynamic and static fluid pressures at the Pitot-static head being used to operate an indicator which is calibrated to indicate the relative velocity between the fluid and body. Alternatively, as is well known, a Venturi tube or its equivalent may be utilised instead of a Pitot-static head and the difference of pressure between two points in the tube used for a similar purpose.

Apparatus which makes use of either a Pitot-static head or Venturi tube as above described suffers from the disadvantages in many applications that the difference of pressure tends to be proportional to the density of the fluid, and not independent thereof, whilst it also tends to vary as the square of the relative velocity between the fluid and the body, and not in proportion thereto. These are disadvantages which are particularly serious in the case of certain types of air-speed indicator or air-distance indicator for use in aircraft as the density of air depends to a marked degree on altitude and temperature, whilst the integration of air-velocities to indicate distance traversed through the air also presents obvious difficulties on account of the "square-law" relationship between pressure difference and relative velocity. This latter disadvantage similarly applies to the use of Pitot-static heads or Venturi tubes or their equivalent in flow-meters for measuring the total flow of a fluid through a pipe or channel in a specified time.

The third system in general use utilises the phenomenon of the cooling of an electrically-heated wire, and consequent decrease of electrical resistance thereof, by the flow past it of the fluid, but such cooling depends on many parameters besides the relative velocity between the said wire and fluid and is not, in general, even approximately proportional to the said relative velocity so that the measurement and integration of this relative velocity again presents great difficulties.

It is therefore an object of the present invention to provide an improved fluid-velocity measuring device which shall not suffer from the disadvantages of the devices above mentioned.

It is well known that vortices are formed when a fluid streams past an obstacle or through an orifice at a velocity greater than a certain critical value and less than another critical value, both values depending upon the dimensions of the said obstacle or orifice and upon the kinematic viscosity of the fluid. If the obstacle be, for example, a cylinder of circular cross-section the longitudinal axis of which is at right-angles to the direction of the flow of the fluid, it is well known that, above a certain velocity of the fluid, vortices tend to be formed on the downstream side of the cylinder at regular intervals and alternately, firstly behind one side or edge of the cylinder and then behind the opposite side or edge, which vortices detach themselves from the cylinder in two nearly-parallel rows and are carried downstream at a velocity substantially proportional to, but somewhat less than, the relative velocity of the fluid. That is to say, the vortices have a slip-velocity which tends to bear a constant ratio to the velocity of the fluid. It is also well known that in each row the vortices are formed at a distance apart which tends to bear a constant ratio to the diameter of the cylinder but to be substantially independent of the relative velocity of the fluid. From these considerations it has been shown that the frequency at which vortices are formed behind either side or edge of the cylinder tends to be proportional to the relative velocity of the fluid and inversely proportional to the diameter of the cylinder, but to depend substantially upon no other factor or parameter, provided that the Reynold's number for the cylinder lies between certain limits. The Reynold's number is defined as the non-dimensional product of the relative velocity of the fluid and the diameter of the cylinder divided by the kinematic viscosity of the fluid.

The phenomenon of alternate vortex-formation in two rows in this way has been described with reference to an obstacle in the form of a cylinder of circular cross-section, but similar considerations apply in varying degrees to any obstacle of cylindrical form with its longitudinal axis at right-angles to the direction of flow of the fluid, even if its cross-section is not of circular shape, provided of course that the said cross-section is not deliberately made of a shape which is streamline in the aerodynamic sense of the word. In all cases the result of the alternate vortex formation in two rows is to generate alternating forces on the obstacle which under suitable conditions will set it in oscillation in a plane perpendicular to the direction of flow of the fluid and may also cause compressional waves of sound in the fluid.

The phenomenon of alternate vortex formation in two rows in this way occurs frequently in the natural world, and is known to be the cause of, for example, the "singing" of telegraph wires in a wind, the "sighing" and "roaring" of wind in trees and the "whistling" of wind through tall grasses. It is also the principle underlying the action of the well-known "Aeolian Harp" and is one of the reasons for the fluttering of a flag in a breeze.

In a somewhat similar manner, vortices tend to be formed at regular intervals and alternately behind the sides of a parallel-sided slit or orifice through which a blade-shaped sheet of fluid is caused to issue into a space containing the same fluid substantially at rest, and as before the frequency at which these vortices are formed alternately behind either edge of the slit tends to be proportional to the velocity of the issuing fluid and inversely proportional to the width of the slit, but to depend substantially upon no other factor or parameter

provided again that the Reynold's number for the slit lies between certain limits. In practice, the vortices formed in this way tend to be weak and unstable in comparison with those formed at the sides of an obstacle and in certain applications of this phenomenon, for example in organ-pipes, a wedge of small angle is located behind the slit at a certain distance therefrom and parallel thereto in order to stimulate production of vortices at a desired frequency.

It has been proposed hitherto to utilise the phenomenon of alternate vortex formation in two rows behind an obstacle as hereinbefore described in an arrangement for measuring the relative velocity between a body and a contiguous fluid comprising a cylindrical member pivoted to the body about an axis perpendicular to the longitudinal axis of said cylindrical member and at one of the ends thereof, said axis of pivoting being parallel to the direction of flow of the fluid. Flow of fluid past such a member causes the formation, in the manner already explained, of two nearly-parallel rows of alternate and equally-spaced vortices, one row forming on each side of the member, and the breaking-away of these vortices alternately from opposite sides of the member imparts an alternating transverse force thereto. As a result, an alternating moment or couple is generated about the axis of pivoting of the member, the frequency of alternation of said moment or couple being substantially independent of the density and temperature of the fluid but proportional to its relative velocity. The cylindrical member is accordingly set into oscillation about the said axis of pivoting at the same frequency as that of the said moment or couple and this frequency is measured by suitable means and the relative velocity of the fluid thereby determined.

This proposed arrangement is, however, a disadvantageous one in that the vortices generated are only in contact with, and can exert substantial pressure on, said cylindrical member for a relatively short period during a cycle, so that the impulses given to the member by the alternating moments or couples are correspondingly small. With a typical cylinder, for example, the diameter of the vortices may be approximately of the same order of size as the radius of the cylinder whereas the distance between successive vortices in the same row may be of the order of eight times the said radius. At the same time, the moment of inertia of a cylindrical member oscillating about an axis perpendicular to its length and located at one of its ends is a maximum for any axis passing through the member so that the angle through which the said member is deflected by the impulses tends to be undesirably small. This disadvantage is made greater by the fact that on any body, such as a ship or aircraft, which is liable to be subjected to local vibration, the cylindrical member would have to be balanced by an equivalent mass positioned on the other side of the said axis from said member, thereby further increasing the moment of inertia of the member and decreasing the general sensitivity.

Furthermore, with the arrangement described, considerable errors in the ultimate indications may arise if the direction of the flow of fluid past the cylindrical member is not accurately parallel with the axis of pivoting about which the said member oscillates, and such parallelism is not easy to ensure in many applications. This disadvantage exists even if the whole arrangement be mounted on a turntable so as to permit rotation about the longitudinal axis of the cylinder in its mean position since it is not inherently self-aligning to the direction of flow of the fluid and extraneous means would have to be provided in order to effect such alignment, particularly if the device were utilised as an anemometer or the like.

It is a further object of this invention therefore to reduce or eliminate the above-mentioned disadvantages and to utilise the phenomenon of alternate vortex-formation in two rows behind an obstacle or orifice for the measurement and/or integration of fluid-velocities in a different and more efficient manner.

According to the invention the improved device for measuring the relative velocity between a body and a contiguous fluid comprises a vane-like element immersed in the fluid and mounted on the body, or on a part fixed relatively thereto, so that the plane of the element lies substantially parallel to the direction of flow of the fluid past the body and so that the element is capable of oscillatory motion about a longitudinal axis substantially at right-angles to the direction of flow of the fluid, and means for generating a double system of travelling vortices in the fluid in such a way as to cause them to impart an alternating moment or couple to the element about its axis of rotation and thereby to cause it to oscillate with a frequency substantially proportional to the relative velocity between the fluid and body.

The means for generating a double series of travelling vortices may comprise either an obstacle or an orifice arranged upstream of the vane-like element. In the case where an obstacle is used this may be combined with the vane-like element, which latter is then formed as a projection or tail on the obstacle, or the obstacle and element may be separate. In the case where an orifice is used this is conveniently formed in the upstream end of a casing which is immersed in the fluid and contains the vane-like element.

It is preferred to dimension the vane-like element in such manner that its length in the direction of fluid flow is such that a vortex on one side of the element is just passing beyond the downstream edge as the next vortex on the same side is beginning to overlap the upstream edge.

The invention will now be described with reference to the accompanying diagrammatic drawings, in which :—

Figures 1 to 7 show by way of example several alternative arrangements of an obstacle and an associated vane-like oscillating element;

Figure 8 shows by way of example an alternative arrangement using an orifice and an associated vane-like element;

Figures 9 and 10 show variations of the arrangement of Figure 8;

Figures 11 to 14 show alternative methods of mounting an oscillating vane-like element;

Figures 15 to 18 show alternative complete systems for the measurement and integration of fluid velocity; and

Figures 19 and 20 show respectively a plan and side elevation, partly in section, of a further device in accordance with this invention.

In the arrangement shown in Figure 1, the vane-like element is combined with the obstacle in a single member and the obstacle is conveniently in the form of a cylindrical rod or tube 1 having a projection or tail 2 extending radially outwardly therefrom and longitudinally of the cylindrical rod or tube so as to form the vane-like element, the whole member being mounted for oscillatory motion about the longitudinal axis 3 of the rod or tube and arranged in the path of flow of the fluid with the tail 2 on the downstream side of the cylindrical rod or tube 1 and with the direction of the depth of the tail substantially parallel to the direction of flow of the fluid. If desired, and as shown in Figure 2, the downstream half of the cylindrical rod or tube 1 may be cut away at 4 to facilitate the production of vortices and the projection or tail 2 tapered from the cut-away rod or tube. The combined member may be either journalled or pivoted in bearings fixed relative to the body, or alternatively may be mounted so as to permit oscillation about a fixed shaft coaxial with the longitudinal axis 3.

The flow of fluid past such a member as depicted in Figure 1 or 2 causes the formation of a double system of vortices 5, 6 as hereinbefore described, which formation may if desired be facilitated by transverse holes 7 cut in the tail 2, and the breaking away of these vortices alternately from opposite sides of the obstacle imparts an alternating transverse moment or couple to the projection or tail 2 of the element about the longitudinal axis, which moment or couple will therefore cause the member to oscillate at the same frequency as the frequency of alternation of the said moment or couple.

The length of the projection or tail 2 is preferably made such that a vortex 5 on one side of the projection or tail is just passing beyond the downsteam end thereof as the succeeding vortex is being formed on the same side near the upstream end, whereupon each vortex acts on the projection or tail for substantially the whole of a cycle and will tend to produce a uniformly-increasing moment or couple about the longitudinal axis. A vortex 6 on the other side of the projection or tail will correspondingly tend to produce a uniformly-increasing moment or couple about the longitudinal axis which is in the opposite sense and which is different in phase by a half-cycle, from which it can easily be shown that the net alternating moment or couple acting about the longitudinal axis tends to be constant in one direction for one half-cycle, and constant in the other direction for the other half-cycle, that is to say it has a waveform which tends to be " square ". The efficiency of such an arrangement is therefore high, and this fact, taken in conjunction with the fact that the moment of inertia of the member about its longitudinal axis is about the minimum for any axis passing through the member, ensures that the sensitivity of the arrangement is very much greater than in the case of the previously known device described above in connection with the prior art.

In a second possible arrangement, the double system of vortices is formed by a separate obstacle placed on the upstream side of the oscillating vane-like element. In such case the obstacle 8 may be, as shown in Figure 3, in the form of a plate arranged at right-angles to the direction of flow of the fluid or, alternatively, may be of cylindrical form with a cross-sectional shape similarly conducive to the formation of vortices. Thus the cross-section of the obstacle 8 may, as shown for example in Figure 4, take the form of a semi-ellipse with its bounding minor axis perpendicular to the direction of flow of the fluid at the downstream end and if desired the plane face of the obstacle corresponding to the said minor axis may have a semi-cylindrical cavity 9 or the like cut into it so as to promote further the formation of vortices. With such arrangements the oscillating element may then take the form of a vane 10, preferably but not necessarily of symmetrical shape about its longitudinal axis 11 of oscillation, the vane being suitably mounted so as to permit oscillation about this longitudinal axis, and having its upstream edge located behind the obstacle with its plane substantially in the extended centre-line of the obstacle and parallel to

the direction of flow of the fluid. Vortices shed by the obstacle from either side or edge will then act on the vane 10 in the manner hereinbefore described so as to impart an alternating moment or couple to it about its longitudinal axis and cause it to be set into oscillation.

As in the case of the previous arrangements it is preferred that the total length of the vane 10 at right-angles to its longitudinal axis should be such that a vortex on one side is just passing beyond the downstream edge thereof as the succeeding vortex on the same side is beginning to overlap the upstream edge, since in this case each vortex is caused to generate a moment or couple on the vane about its longitudinal axis which tends to start at a maximum in one sense or direction, to decrease steadily to zero as it passes the longitudinal axis, and then to increase to a maximum in the other sense or direction. A vortex on the other side of the vane will correspondingly tend to generate a moment or couple of similar magnitude and form which is, however, of opposite sense and different in phase by half a cycle, from which it can easily be shown that, as in the case of the previous arrangement of this invention, the resultant alternating moment or couple about the longitudinal axis has a waveform which tends to be " square ". Taking into account, therefore, the fact that a vane of the type just described, especially if symmetrical about the axis of oscillation, may be very light and of small moment of inertia, it is clear that this arrangement of the present invention may be of even greater sensitivity than the one previously described.

It will be appreciated that the arrangement of the obstacle and vane-like element may take many forms. For example, it may be preferred in some cases to make greater use of the fact that the vortices behind an obstacle are generated in two rows by constructing the vane-like element in the form shown in Figure 5. In this Figure the obstacle 8 may be of any suitable shape such as that depicted in Figure 4, whilst the vane-like element comprises two parallel and similar vanes 12 and 13 rigidly connected together by a transverse member 14 and adapted to vibrate about a common longitudinal axis 11. The distance apart of the two vanes may then be made such that each lies in or near the line of centre of one of the two rows of vortices so as to be acted upon most efficiently by the said vortices, whilst as in the previous arrangement, the total length of each vane in the direction of flow of the fluid is preferably made nearly equal to the distance apart of successive vortices in the same row.

With certain types of obstacle such as those of circular cross-section or of the wedge-shaped section depicted in Figure 6 it is found that the rows of vortices diverge at an angle immediately behind the obstacle and do not become substantially parallel until a considerable distance has been traversed by the vortices downstream. In such a case the vanes 12 and 13 depicted in Figure 5 may for greater efficiency be inclined towards one another at a corresponding angle as depicted in Figure 6. Alternatively and for a similar purpose the vane-like element may, as depicted in Figure 7, be shaped in the form of a dart 15 having an appropriate angle at its leading edge, the rear end of the dart being preferably cut away as shown to reduce its moment of inertia about the longitudinal axis as much as possible.

In a further arrangement, an orifice is used to produce the double system of vortices. As shown in Figure 8 such an orifice may conveniently take the form of a parallel-sided slit 16 located in the nose or upstream end of a suitable casing 17 immersed in the fluid, the slit having the direction of its length perpendicular to the normal direction of flow of the fluid relative to the body. The casing may be either an already-existing part of the body, for example the fuselage or a wing of an aircraft in the particular case when the arrangement is being used as an air-speed and/or air-distance indicator, or alternatively the said casing may be a special part attached to the body and immersed in the fluid, in which case it is preferably of a cylindrical form having its longitudinal axis substantially at right-angles to the direction of flow of the fluid and having a streamline shape in cross-section, the casing being then so positioned that its axis of symmetry in cross-section is substantially parallel to the direction of flow of the fluid relative to the body. In all cases it is designed that the parallel-sided slit 16 shall produce a blade-shaped sheet of fluid which flows through the slit at a velocity equal or proportional to the velocity of the fluid relative to the body, and which enters the casing 17 and generates therein a double system of vortices behind the edges of the slit in the manner hereinbefore described, after which the sheet of fluid is permitted to escape from the casing through suitable vents 18 located in its downstream end.

The double system of vortices formed behind the edges of the parallel-sided slit in this way is then utilised as in the previous arrangements to cause a vane-like element 10 positioned behind the slit 16 on the downstream side, with its plane substantially parallel to the direction of flow of the sheet of fluid issuing therefrom, to oscillate about a longitudinal axis 11 with a frequency substantially proportional to the velocity of the

sheet of fluid and independent of its density, the axis being parallel to the sides of the slits and symmetrically located with respect thereto.

In one form of this arrangement the longitudinal axis 11 may be located at approximately one-fifth of the distance from the upstream edge of the vane 10 to its downstream edge, so that the dynamic centre of pressure on the vane is always on the downstream side of the longitudinal axis and the vane is self-aligning to any small deviations in the direction of flow of the sheet of fluid issuing from the orifice. The vane may then be located so that its upstream edge is approximately in the plane of, or immediately behind the plane of, the downstream edges of the slit in the casing.

If desired, the vane-like element may, as depicted in Figure 9, take a similar form to that depicted in Figure 5, and comprise two parallel and similar vanes 12 and 13 rigidly connected together by a transverse member 14 and adapted to vibrate about a common longitudinal axis 11.

The production of vortices behind the downstream edges of the slit may in some cases be facilitated as shown in Figure 10 by bevelling the sides of the slit 16 on their upstream faces and if desired also a fixed wedge 19 of small angle may be located for the same purpose inside the casing with its fine edge parallel to the slit and symmetrical with respect thereto. In the latter case, the oscillating element 10 may then be located on the downstream side of the wedge 19 and along its extended centre-line, and may be of symmetrical shape about its longitudinal axis of oscillation.

In all forms of this third arrangement is it preferred that, as in the case of the previous arrangements, and for the reasons hereinbefore stated, the length of the oscillating element 10 at right-angles to its longitudinal axis should be such that a vortex on one side is just passing beyond the downstream edge thereof as the succeeding vortex on the same side is beginning to overlap the upstream edge.

In all the arrangements of the invention hereinbefore described it is preferred that the oscillating vane-like element, together with any other attachments on the spindle or the like constituting the longitudinal axis thereof (hereinafter called the complete oscillating element), should be balanced as far as possible in every plane at right-angles to this axis, such balancing being desirable in order that the complete element should not be forced into spurious oscillation by any vibration of the body upon which it is mounted. Immunity from such spurious oscillation is obviously of particular importance when the body is a ship or aircraft, and may be preferably effected by suitable shaping of the complete element and/or addition to the complete element of suitably-positioned masses in each of the said planes, but if such a procedure be impracticable, discrete masses may be rigidly attached to the spindle or the like at suitably chosen points, so that the complete element is not only balanced statically but also dynamically. Preferably also the complete element, with or without the discrete masses, is so constituted that its moments of inertia about any two axes through the centre of gravity of the complete element at right-angles to one another and to the longitudinal axis are the same.

In all the arrangements hereinbefore described it is also preferred that there should be provided sufficient elastic or resilient control of the complete element to ensure that the element is dynamically stable and that the vane is maintained substantially in its correct alignment along the direction of flow of the fluid relative to the body despite the action of non-periodic and random moments or couples which may arise from temporary variations in the direction of flow of the fluid or from like causes.

The means whereby elastic or resilient control may be exerted on the complete element may comprise any known device such as springs or suitably-placed strips of rubber-like material and, in the particular cases when the vane-like element is immediately on the downstream side of a wedge behind an orifice, a part or whole of the control may be provided by making the upstream edge of the vane V-shaped and arranging for this edge to engage in a corresponding V-shaped slot on the downstream side of the wedge, the slot being lined with a suitable strip of rubber-like material 20 as shown in Figure 10.

The use of springs to provide a resilient control of the oscillating element is illustrated in Figure 11 which shows a sectional view of an obstacle 24 and vane-like element 25 mounted for measuring the velocity of fluid flow in a conduit 26. The vane 25 is mounted on a spindle 27 which passes through apertures in the conduit 26 and is located in bearings 23 in the fixed body 28. A spring 29 secured at its ends to the fixed member 28 and the spindle 27 applies the required control.

Alternatively, and particularly in cases where the frequencies of oscillation of the complete element, corresponding to the range over which it is desired to measure relative velocities between the body and the fluid, are all high it may be preferred, as shown in Figure 12, to exert elastic control by means of the torsion of one or more thin rods, tubes, or ligaments forming a co-axial extension of the spindle 27 or the like of the complete element 25 and fixed at the

outer end or ends to a suitable point or points on the body 28, or on a part thereof. In a further alternative shown in Figure 13, efficient elastic control may under similar circumstances be exerted by means of pairs of taut fibres or ligaments 30 arranged in parallel with one another in a manner similar to that used for the well-known " bi-filar suspension ", the component fibres or ligaments of each pair being normally parallel to, and equi-distant from, the longitudinal axis 31 of the complete element 25 and being attached at one end to the element and at the other end to a suitable fixed point on the body 28, or on a part thereof.

In many applications of the invention, especially in cases where the fluid is a liquid, it may be desirable to isolate or seal off the vane or oscillating element from the other attachments on its spindle or the like, especially those attachments which are associated with the means provided for measuring and/or integrating the frequency of oscillating of the element. Such isolation or sealing off is particularly desirable in, for example, ship's logs and flow-meters for measuring the flow of a liquid or a gas in a pipe, and may be provided, as shown in Figure 14, by one or more fluid-tight glands 32 provided, with a washer 32 and an elastic sealing member 33 through which the spindle 27 is caused to pass. The elastic sealing members may be, for example, annular rings of rubber or like substance which are forced under pressure into intimate contact with the spindle, or may alternatively be in the form of tubular sleeves of rubber or like substance bonded internally to the spindle and externally to the body or a part thereof. Conveniently with such an arrangement elastic or resilient control of the oscillating element may then be provided, in whole or in part, by the elastic sealing members, and, in the case where annular rings of rubber or the like substance are used, adjustment within certain limits of the magnitude of the control may be effected *in situ* by corresponding adjustment of the pressures on the annular rings. In both cases, of course, the elastic control of the oscillating element may be arranged to have a predetermined value within certain limits by suitable choice of the " Shore Hardness " or elasticity of the rubber or like substance used to form the sealing members.

In all the arrangements hereinbefore described it is preferred that the elastic or resilient control of the complete element, and also the total moment of inertia of the complete element about its longitudinal axis, should be as small as possible consistent with dynamic stability, since under these conditions the alternating moment or couple on the vane, due to the passage of the vortices, has for the most part only to overcome the damping moment or couple on the vane due to its resulting oscillation. It can be shown that in most applications of the invention both the above-mentioned moments or couples tend to be proportional to the density of the fluid and to the square of its velocity relative to the body and therefore the amplitude of oscillation of the vane, and thus its sensitivity, tends to be constant and independent of both the density and relative velocity of the fluid, whilst the change of displacement of the vane from one side to the other during a half-cycle of oscillation takes place with substantially uniform angular velocity which is proportional to the relative velocity of the fluid, that is to say the displacement has a waveform which is nearly " triangular ". The characteristic in particular of constant sensitivity is obviously very advantageous, especially in applications of the invention where the fluid is a gas such as air, and where its density may vary widely, as is often the case during the flight of an aircraft.

The means for measuring and/or integrating the frequency of oscillation of the complete element and for translating it into a reading on an instrument calibrated to indicate the relative velocity between the fluid and the body and/or the total flow of the fluid past the body in a specified time, may comprise any known method for measuring the frequency of a mechanical vibration, such as a plurality of calibrated and tuned reeds, and any known method for integrating the frequency of a mechanical vibration such as the use of a mechanical counter or register, but will conveniently comprise electrical means for detecting the mechanical oscillation of the element and generating from such oscillation an alternating electrical current of the same frequency, which frequency can then be measured and/or integrated by any known method.

The means for detecting the mechanical vibration and for generating from such oscillation an alternating electrical current of the same frequency may comprise any suitable type of electrical transducer such as is used, for example, in gramophones or in devices for measuring the vibration of machinery or structures such as aircraft. Thus the said transducer may be, for example, of either the moving-coil or moving-iron type, depending on the particular application of the invention, or on the other hand one of the well-known resistance types acting on the same principle as, for example, the carbon microphone or the resistance strain-gauge. Alternatively, the transducer may be of the capacitance type acting on the same principle as the so-called

condenser microphone, or may utilise either the piezo-electric effect, as in the crystal microphone, or else the magneto-striction effect. In all cases it is preferred that the transducer shall be responsive primarily to rate-of-change of displacement rather than to displacement *per se* of the oscillating element, so that the ultimate readings are not substantially affected by non-periodic and random displacements of the element from its normal position of equilibrium.

In some cases it is contemplated that the vane-like element may itself consist of or form part of the transducer. For example the vane might be made of a piezo-electric material so that when it is strained about its longitudinal axis of oscillation it generates electric currents.

One known type of electrical transducer suitable for many applications of the invention comprises an armature in the form of an I-shaped block of laminations of magnetic material which is rigidly attached to the spindle for oscillation with the complete oscillating element and so as to form with the latter a cross having symmetrical arms. The armature in its normal position of equilibrium rests symmetrically between the limbs of two fixed and oppositely-facing U-shaped blocks of laminations of magnetic material and of identical construction, so that two pairs of equal air-gaps are created, one pair at each end of the armature with the corresponding air-gaps of each pair at opposite sides of the relevant end of the armature. A magnetic potential from, for example, a permanent magnet is applied to the two U-shaped blocks in series, thereby causing substantially equal magnetic fluxes to stream in parallel across each of the two pairs of air-gaps and forming in effect a magnetic analogy of the well-known "Wheatstone Bridge". Thus as a result of the equality of the air-gaps and consequent of their magnetic reluctance when the armature is in its normal position of equilibrium, no magnetic flux flows in either direction along the armature when in the position of equilibrium but, when the said armature oscillates with the oscillating element, the balance of what may be called the "Magnetic Wheatstone Bridge" is upset first in one direction and then in the other, and an alternating magnetic flux is accordingly caused to flow in the armature at the same frequency as that of the mechanical oscillation. This alternating magnetic flux is in turn caused to generate an alternating electrical voltage in a suitable fixed coil linked with the armature.

As shown diagrammatically in Figure 15, the alternating current generated by the mechanical oscillations of the element 35 in a suitable electrical transducer 36 such as that just described may then be amplified, if required, by known means and the frequency of the resulting electrical current output thereafter measured directly by a frequency meter 37 of known form such as, for example, is shown in my British Patents Nos. 384,703 and 422,202, the frequency meter being suitably calibrated to indicate the relative velocity between the body and fluid. At the same time, the frequency may be integrated, if desired, to give a measure of the total fluid flow in a specified time by applying the alternating electrical current output to a self-starting synchronous a.c. electrical motor 38, the revolutions of which in a specified time may be counted by any known form of mechanical counter 39 calibrated in terms of fluid flow or, in the case of logs or distance indicators, the distance traversed by the body through the fluid.

Alternatively, as shown in Figure 16, the output of the electrical transducer 36 may, if required, be amplified and the amplified output limited in amplitude and converted by known electronic or magnetic means 40 into an alternating electrical current, or in some cases an alternating magnetic flux, the waveform of which is substantially "trapezoidal" and of constant amplitude at all frequencies. The alternating current or magnetic flux may then be differentiated by the known electronic or magnetic means 40 so as to produce discrete pulses of voltage or current of alternate sign, the number of said pulses of one sign per second being, of course, the same as the original frequency of the mechanical oscillations of the complete element. Voltage pulses produced in this way tend to have a peak value of voltage which is proportional to frequency, but their form is such that when applied to a circuit comprising resistance alone, or resistance and inductance in series, the total quantity of electricity passed through the circuit as the result of each pulse is substantially constant and independent of frequency.

The said discrete pulses may then be rectified, if desired, and applied to any known circuit 41, electronic or otherwise, which is adapted to the measurement of pulse-frequency, and as a result of which a reading may be caused to appear on an instrument 42 calibrated in terms of the relative velocity between the body and the fluid.

One type of pulse frequency measuring circuit which is especially convenient for logs in small ships which have no electrical supply is shown in Figure 17 and comprises an electrical transducer 45 of the "Magnetic Wheatstone Bridge" type as already described, the output from which is applied to the primary coil 46 of a saturable transformer 47, in which coil the number of turns

is so related to the applied voltage that a part of the core of the transformer is magnetically saturated each half-cycle. A secondary coil 48 wound on another part of the core of the transformer is connected in series with a bridge rectifier 49, the rectified output from which is then passed through a d.c. current-measuring instrument 50 such as a moving coil milliammeter. The changes of magnetic flux from saturation of a part of the core in one direction to saturation in the other direction accordingly produce discrete pulses of current in the secondary circuit of the type hereinbefore described, which pulses after rectification pass through the milliammeter in the same direction and develop therein an average current proportional to the frequency of oscillation of the oscillating element since the quantity of electricity in each pulse is substantially constant. The milliammeter may accordingly be calibrated in knots or as otherwise desired, final adjustment *in situ* of its readings to a correct value being effected by such means as manipulation of a variable shunt 51 in parallel with the coil of the instrument.

If required, known arrangements comprising, for example, an auxiliary coil 52 on a suitable magnetic circuit in shunt may be incorporated in the saturable transformer 47 to compensate for any errors which may arise from incomplete saturation of the core of the saturable transformer each half-cycle. Similarly any errors in the said ultimate indications or readings which may arise from alteration, due to temperature changes, of the ohmic resistances of the secondary coil of the saturable transformer, of the bridge rectifier, and of the coil of the milliammeter may be substantially eliminated by incorporating in the secondary circuit of the saturable transformer a suitably placed resistor 53 of appropriate value, said resistor being formed of a material such as certain semi-conductors which have a large and negative temperature-coefficient of resistivity.

The discrete pulses produced by any of the means hereinbefore described may also, or alternatively, be rectified if desired, and applied to any known circuit, electronic or otherwise, which is adapted to the counting of the total number of pulses generated in a specified time, and as a result of which a reading may be caused to appear on an instrument calibrated in terms of the total flow of the fluid past the body in the same time. Many examples of such circuits are known, and are employed, for example, in connection with research work in nuclear physics or in computing devices.

If, for example, a circuit be used in which, as in the case of the pulse-frequency measuring circuit described in connection with Figure 16, a d.c. current is ultimately produced which is proportional to the pulse-frequency, the current before or after amplification may be applied to a d.c. motor 43 of the so-called integrating type having the property, like the well-known d.c. current supply meter, that the number of revolutions developed per second is always proportional to the applied current or voltage, whereupon the total number of revolutions in a specified time, which may be determined by any known type of mechanical counter 44, is a measure of the total flow of fluid past the body in a specified time, or of the distance traversed by the body through the fluid. Alternatively, the total quantity of electricity passed in a given time when such a d.c. current varying proportionally to the pulse-frequency is produced, and which quantity is again a measure of the total flow of fluid, may be determined if desired by the use of a suitable electrolytic-meter acting on the same principle as the meters of this type used in supply systems.

If preferred, so-called triggered electronic counting circuits may be used which may, for example, comprise a plurality of so-called "scale-of-two" counters of the well-known "flip-flop" type connected together in cascade, or a plurality of so-called "scale-of-ten" counters connected together in cascade, or any suitable combination of such counters arranged so as to actuate ultimately a mechanical counter or register suitably calibrated in terms of total fluid flow. Alternatively, or in addition, a plurality of so-called "transfer tubes", such for example as are known by the Registered Trade Mark "Dekatron", may with their associated circuits be employed in cascade, and in such a case a mechanical counter or register may be omitted and the indications of total fluid flow caused to appear on the "transfer tubes" themselves in the form of moving spots of light against appropriately calibrated circular dials.

In the circuit shown in Figure 18, which is particularly adapted to both the measurement and integration of pulse frequencies, and hence of fluid velocities, in cases where it is desired to show the indications of both fluid velocity and total fluid flow on several "repeater" instruments, discrete voltage pulses of alternately opposite sign, and generated in the manner hereinbefore described with reference to Figure 16, are applied in push-pull to the control grids of two similar gaseous discharge tube 60 of either the cold cathode type or else of the hot cathode type generally known as "Thyratrons". The said pulses are applied through resistance-capacity networks 61 so designed as to ensure that the amplitudes of the resulting positive voltage pulses actually

appearing on the control grids are substantially constant and independent of frequency, whilst the control grids are normally biased so that in the absence of positive voltage pulses the discharge tubes are stable and quiescent, although the positive voltage pulses are of sufficinet magnitude in themselves to fire the discharge tubes.

The cathodes of the discharge tubes are connected together in common to one side of a reservoir capacitor 62, and between the other side of the reservoir capacitor and the anode of each of the two discharge tubes are connected equal capacitors 63, 64, the latter two capacitors each having a capacity very much smaller than that of the reservoir capacitor. Each of the capacitors 63, 64 (hereinafter called the discharge capacitors) is connected at its end common with the anode of its respective discharge tube through a similar anode resistor 65, 66 to a stabilised source of high tension voltage, the circuits therefrom being completed in such a way that a discharge-capacitor can be charged through its associated anode resistor to very nearly the full value of the stabilised high tension voltage when its associated discharge tube, which is effectively in parallel with it, is quiescent.

The time constant of each of the circuits comprising an anode resistor and its associated discharge-capacitor in series with it is made such that the discharge-capacitor can become substantially fully charged in the interval between the occurrence of two consecutive positive pulses of the same sign even at the highest designed pulse frequency, but the application of such a positive pulse to the control grid of its associated discharge tube fires the latter and permits the discharge-capacitor to discharge very rapidly into the reservoir-capacitor 62 until the voltage of the discharge-capacitor falls to the same value as that of the reservoir-capacitor plus the small and substantially constant anode-to-cathode voltage drop in the discharge tube *per se* during discharge, whereupon the discharge is extinguished. This process of transference of charge to the reservoir-capacitor 62 is then repeated alternately by the two discharge tubes in response to the discrete voltage pulses as they are received.

The reservoir-capacitor 62 has in parallel therewith a leakage path comprising impedances so chosen in relation to the reservoir-capacitor that both the peak and average values of the resulting voltage appearing across the said reservoir-capacitor as the result of the above-mentioned process of repeated charge transference are small in comparison with the stabilised high tension voltage, whence it follows that each of the discharge capacitors is very nearly fully discharged when its associated discharge tube fires and, having been originally charged to a constant voltage approximately equal to that of the stabilised high tension supply, delivers a substantially constant quantity of electricity to the reservoir-capacitor on each such discharge. It therefore follows that under normal conditions the average current through the leakage path in parallel with the reservoir-capacitor, which of course equals the total quantity of electricity received per second by the said reservoir-capacitor, is substantially proportional to the original pulse frequency, and hence to the fluid velocity.

The impedances in the leakage path across the reservoir-capacitor 62 may comprise, in series with one another and a suitable inductor 67, one or more d.c. current measuring instruments such as milliammeters 68, and also the field coils 69 of one or more d.c. motors of the integrating type, the armatures 70 of which are supplied through appropriate resistors with constant d.c. voltage. The magnetic circuit of the field of each of these motors has sufficiently large air-gaps therein to ensure that the field flux is substantially proportional at all times to the field current, whence it follows that the torque developed in the motor is also proportional to the said field current, since the armature current is constant.

In view of the proportionality between the current in the said leakage path and pulse frequency, it is apparent that the milliammeters 68 or equivalent instruments may be calibrated directly in terms of pulse frequency, and hence of fluid velocity. It is also arranged that the torque developed in each of the integrating motors is absorbed substantially completely in overcoming only the counter-torque developed by some form of brake 71 such as the well-known "eddy current brake", which brake is coupled mechanically to the armature of the integrating motor and in which brake the counter-torque varies in proportion to the angular velocity of the armature. The armature will therefore tend to rotate at all times at an angular velocity proportional to the field current, and thus to pulse frequency, so that the total number of revolutions of the armature in a specified time, which may be determined by any known type of mechanical counter or register 72, is a measure of the total flow of fluid past the body in a specified time, or of the distance traversed by the body through the fluid.

If desired, means may be incorporated in any of the arrangements hereinbefore described whereby the oscillating vane-like element, which oscillates at a frequency proportional to the relative velocity between the body and the contiguous fluid, may be caused to orientate itself automatically along the direction of flow of the said fluid,

and the said means may make use of the fact that each of the arrangements of obstacle and oscillating element hereinbefore described will, if permitted to do so, naturally tend to align itself along the direction of flow of the fluid by virtue of what may be called " weather-vane action ".

In, for example, the arrangement first described (Figure 1) in which the obstacle and oscillating element are combined in one common member such as a cylindrical rod with a longitudinal tail on the downstream side, the common member together with its associated electrical transducer may be mounted on a rotatable turntable having a moment of inertia high compared with that of the common member, so that the whole assembly will tend naturally to turn, by virtue of the " weather-vane action ", until the tail is aligned along the direction of flow of the fluid, whilst the oscillations of the complete element, due to the flow of the fluid past it, will be superimposed upon this rotation. Due, however, to the very great difference between the moments of inertia of the complete element and the turntable, the response of the electrical transducer to the generally rapid oscillations of the combined member will not be appreciably affected by slow rotation of the turntable due to change of direction of flow of the fluid. The effect of rotation of the turntable will be smaller still if, as is preferred, the electrical transducer is primarily responsive to rate-of-change of displacement and not to displacement *per se*.

In the case where the oscillating element is located behind a separate obstacle, the obstacle with oscillating element and electrical transducer or vibration pick-up may again be mounted as a complete assembly on a rotatable turntable capable of rotation about an axis perpendicalur thereto in the plane of the centre line of the obstacle and suitably chosen so as to give maximum " weather-vane " action. Figures 19 and 20 illustrate the case shown in Figure 8 in which the oscillating element 10 is located behind an orifice 16 in a streamline casing 17. In such arrangement the casing, with oscillating element and electrical transducer 73, may likewise be mounted as a complete assembly on a rotatable turntable 74 capable of rotation about an axis perpendicular thereto in the plane of the centre line of the casing 17 and located at a point forward of the dynamic centre of pressure of the casing.

In all the above-mentioned arrangements, suitable known damping means are preferably provided to ensure that unwanted oscillations of the turntable and its associated parts about the desired line of orientation are effectively suppressed, and slip-rings or the like are preferably provided for the purpose of taking off the alternating electrical voltages developed in the electrical transducer whilst permitting substantially free rotation of the turntable.

If desired also, the orientation of the turntable 74 and its associated parts relative to the body, and hence the direction of the flow of the fluid relative to the body, may be communicated to a distance by making use of any known system for remote indication of angular position, such, for example, as that generally known under the Registered Trade Mark " Selsyn ", and depicted schematically at 75, whilst the components of the velocity of the fluid relative to two chosen axes at right-angles to one another in the body may be determined in any known way, such as by the use of so-called " sine-cosine resolvers " or suitably wound potentiometers.

WHAT I CLAIM IS :—

1. A device for measuring the relative velocity between a body and a contiguous fluid comprising a vane-like element immersed in the fluid and mounted on the body or a part fixed relatively thereto, so that the plane of the element lies substantially parallel to the direction of flow of the fluid past the body, and so that the element is capable of oscillatory motion about a longitudinal axis substantially at right-angles to the direction of flow of the fluid, and means for generating a double system of travelling vortices in the fluid in such a way as to cause them to impart an alternating moment or couple to the element about its axis of rotation and thereby to cause it to oscillate with a frequency substantially proportional to the relative velocity between the body and the fluid.

2. A device as claimed in Claim 1, in which the means for generating a double system of travelling vortices comprises an obstacle arranged upstream of the vane-like element and with its central longitudinal axis parallel with the axis about which the element oscillates.

3. A device as claimed in Claim 2, in which the obstacle and vane-like element are combined in a single member, the obstacle comprising a cylindrical rod or tube and the element comprising an extension or tail extending radially outwards from the rod or tube, the whole being mounted for oscillatory motion about the central longitudinal axis of the rod or tube.

4. A device as claimed in Claim 2, in which the obstacle and vane-like element are formed as separate members and are disposed so that the upstream edge of the element is spaced from the downstream edge of the obstacle.

5. A device as claimed in any of Claims 2, 3 or 4, in which the downstream edge of the obstacle is shaped to facilitate the forma-

tion of vortices as by forming the said edge with an undercut or recess.

6. A device as claimed in Claim 1, in which the means for generating a double system of vortices comprises an orifice located in the upstream end of a casing which may form part of the said body and which is immersed in the fluid, the vane-like element being mounted within the casing with its plane substantially parallel with the sheet of fluid flowing through the orifice.

7. A device as claimed in Claim 6, in which the vane-like element is mounted for oscillating movement about a longitudinal axis positioned upstream of the dynamic axis of pressure on the element.

8. A device as claimed in Claim 6 or Claim 7, in which in order to facilitate the generation of vortices there is provided within the casing and adjacent the orifice a wedge of small angle arranged with its edge parallel with the orifice and symmetrical thereto.

9. A device as claimed in Claim 8, in which the axis of the vane-like element is located in the plane of symmetry of the wedge-side of the wedge and in a plane of symmetry of the vane.

10. A device as claimed in any of Claims 6 to 9, in which the casing is of streamline shape in cross-section and is provided with a vent at its downstream end.

11. A device as claimed in any preceding claim, in which the vane-like element is of such length in the direction of the flow of fluid that a vortex on one side is just passing beyond the downstream edge as the succeeding vortex on the same side is beginning to overlap the upstream edge.

12. A device as claimed in any preceding claim, in which the complete oscillating element, that is the vane-like element and any part that moves therewith, is balanced both statically and dynamically in every plane at right-angles to the axis of oscillation.

13. A device as claimed in any preceding claim, in which the movement of the vane-like element is subjected to an elastic or resilient control to maintain said element dynamically stable.

14. A device as claimed in Claim 13, in which the element is mounted immediately on the downstream side of a separate obstacle or a wedge located behind an orifice and in which the upstream edge of the element is connected with the obstacle or wedge by resilient means.

15. A device as claimed in Claim 13, in which the elastic control is effected by the torsion of thin rods or tubes which form the spindle or an extension thereof on which the vane-like element is mounted for oscillation.

16. A device as claimed in Claim 13, in which the elastic control is effected by mounting the vane-like element on a bi-filar suspension, the component ligaments of which are arranged parallel with and equidistant from the axis of oscillation of the element.

17. A device as claimed in Claim 13, in which the elastic control is effected by mounting a spindle supporting the vane-like element in bearing with intervening elastic material.

18. A device as claimed in Claim 17, in which the elastic material also acts to provide a fluid tight gland.

19. A device as claimed in any preceding claim, in which the vane-like element and associated obstacle or orifice form a unit which is so mounted that it is self-orientating for changes in the direction of fluid flow relative to the body.

20. A device as claimed in Claim 19, in which means is provided for measuring and/or indicating such change in orientation relative to the body.

21. A device as claimed in any preceding claim, including means for measuring and indicating the frequency of oscillation of the vane-like element.

22. A device as claimed in Claim 21, including an electrical transducer responsive to the oscillation of the vane-like element to generate an alternating electric current of the same frequency.

23. A device as claimed in Claim 22, including means for measuring and indicating the frequency of said electric current.

24. A device as claimed in Claim 22 and Claim 23, including means for integrating the frequency of the electric current.

25. A device for measuring the relative velocity between a body and a contiguous fluid substantially as herein described with reference to any of Figures 1 to 14 and Figures 19 and 20 of the accompanying drawings.

26. A device for measuring and indicating the relative velocity between a body and a contiguous fluid substantially as herein described with reference to any of Figures 1 to 14 and 19 and 20 in combination with any of Figures 15 to 18 of the accompanying drawings.

STEVENS, LANGNER,
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PROVISIONAL SPECIFICATION.

Improvements in or relating to Apparatus for the Measurement and Integration of Fluid-Velocities.

I, WILLIAM GEORGE BIRD, a British Subject, of 11 Cranbrook Road, Redland, Bristol 6, do hereby declare this invention to be described in the following statement:—

This invention concerns improvements in or relating to apparatus for the measurement and integration of fluid-velocities and more particularly relates to devices for the measurement of the relative velocity between a body and a contiguous fluid and/or of the total flow of the fluid past the body in a specified time. Such devices are applicable for use as anemometers, as ship's logs or leeway-indicators, and as air-speed indicators or air-distance indicators for aircraft, or alternatively as flow-meters to measure the velocity of flow of a fluid through a pipe or channel and/or to measure the total quantity of fluid passing a given point in the pipe or channel in a specified time, or for any other similar application.

There are three systems in general use at the present time for measuring the relative velocity between a body and a contiguous fluid. In one of these systems, an impeller or rotor is rotatably pivoted on the body, or on a part fixed relatively to the body, and is immersed in the fluid, said impeller or rotor having either, as for example is the case in a windmill, inclined blades radial to its axis of rotation with the latter arranged substantially along the direction of flow of the fluid relative to the body or, as is the case in the well-known Robinson anemometer, cups or the like on arms radial to the axis of rotation with the latter arranged substantially at right-angles to the direction of flow of the fluid relative to the body. Flow of the fluid relative to the body causes the impeller or rotor to rotate with an angular velocity dependent on the relative velocity between the body and the fluid and this rotation may operate, by electrical or mechanical means, an indicator which is suitably calibrated to indicate the said relative velocity.

Such arrangements using an impeller or rotor suffer in many applications from the disadvantage that the angular velocity of the impeller or rotor is not, as it is desirable that it should be, accurately proportional to the relative velocity between the fluid and the body and independent of the density of the fluid unless the impeller or rotor can rotate completely freely without frictional or other constraint, and such a completely free rotation is obviously very difficult to achieve and maintain in practice. Furthermore, the resistance to the flow of the fluid of the impeller or rotor with its mounting may be considerable, and in some applications, such as in high-speed aircraft for example, may be very objectionable for this reason.

In the second system, a so-called Pitot-static head is fixed on the body, or on a part fixed relatively thereto, and is immersed in the fluid, the difference between the dynamic and static fluid pressures at the Pitot-static head being used to operate an indicator which is calibrated to indicate the relative velocity between the fluid and the body. Alternatively, as is well known, a Venturi tube or its equivalent may be utilised instead of a Pitot-static head and the difference of pressure between two points in the tube used for a similar purpose.

Apparatus which makes use of either a Pitot-static head or Venturi tube as above described suffers from the disadvantages in many applications that the difference of pressure tends to be proportional to the density of the fluid, and not independent thereof, whilst it also tends to vary as the square of the relative velocity between the fluid and the body, and not in proportion thereto. These are disadvantages which are particularly serious in the case of certain types of air-speed indicator or air-distance indicator for use in aircraft as the density of air depends to a marked degree on altitude and temperature, whilst the integration of air-velocities to indicate distance traversed through the air also presents obvious difficulties on account of the "square-law" relationship between pressure difference and relative velocity. The latter disadvantage similarly applies to the use of Pitot-static heads or Venturi tubes or their equivalent in flow-meters for measuring the total flow of a fluid through a pipe or channel in a specified time.

The third system in general use utilises the phenomenon of the cooling of an electrically-heated wire, and consequent increase of electrical resistance thereof, by the flow past it of the fluid, but such cooling depends on many parameters besides the relative velocity between the said wire and fluid and is not, in general, even approximately proportional to the said relative velocity so that the measurement and integration of this relative velocity again presents great difficulties.

It is therefore one object of the present invention to provide a fluid-velocity measuring device for measuring and integrating the relative velocity between a body and a contiguous fluid the operation of which is substantially independent of the density and temperature of the fluid, and in which a suitably-located element is caused to oscillate by the flow of the fluid past it at a frequency substantially proportional to the relative velocity between the body and the fluid but dependent upon no other property of the fluid. Means may then be provided for measuring the said frequency, whereby the relative velocity may be readily determined, and means may be also provided if desired for integrating the said frequency with regard to time, that is to say for determining the total number of oscillations of the element in a specified time, whereby the total flow of the fluid past the body in the same time may be likewise determined.

The invention makes use of the principle of the formation of vortices when a fluid streams past an obstacle or through an orifice at a velocity greater than a certain critical value and less than another critical value, both values depending upon the dimensions of the said obstacle or orifice and upon the kinematic viscosity of the fluid. If the obstacle be, for example, a cylinder of circular cross-section the longitudinal axis of which is at right-angles to the direction of the flow of the fluid, it is well known that, above a certain velocity of the fluid, vortices tend to be formed on the downstream side of the cylinder at regular intervals and alternately, firstly behind one side or edge of the cylinder and then behind the opposite side or edge, which vortices detach themselves from the cylinder in two nearly-parallel rows and are carried downstream at a velocity substantially proportional to, but somewhat less than, the relative velocity of the fluid. That is to say, the vortices have a slip-velocity which tends to bear a constant ratio to the velocity of the fluid. It is also well known that in each row the vortices are formed at a distance apart which tends to bear a constant ratio to the diameter of the cylinder but to be substantially independent of the relative velocity of the fluid. From these considerations it has been shown that the frequency at which vortices are formed behind either side or edge of the cylinder tends to be proportional to the relative velocity of the fluid and inversely proportional to the diameter of the cylinder, but to depend substantially upon no other factor or parameter, provided that the Reynold's number for the cylinder lies between certain limits. The Reynold's number is defined as the non-dimensional product of the relative velocity of the fluid and the diameter of the cylinder divided by the kinematic viscosity of the fluid.

The phenomenon of alternate vortex-formation in two rows in this way has been described with reference to an obstacle in the form of a cylinder of circular cross-section, but similar considerations apply in varying degrees to any obstacle of cylindrical form with its longitudinal axis at right-angles to the direction of flow of the fluid, even if its cross-section is not of circular shape, provided that the said cross-section is substantially symmetrical about a line parallel to the direction of the flow of the fluid, and provided, of course, that the said cross-section is not deliberately made of a shape which is streamline in the aerodynamic sense of the word. In all cases the result of the alternate vortex-formation in two rows is to generate alternating forces on the obstacle which under suitable conditions will set it in oscillation in a plane perpendicular to the direction of flow of the fluid and may also cause compressional waves of sound in the fluid.

The phenomenon of alternate vortex-formation in two rows in this way occurs frequently in the natural world, and is known to be the cause of, for example, the "singing" of telegraph-wires in a wind, the "sighing" and "roaring" of wind in trees and the "whistling" of wind through tall grasses. It is also the principle underlying the action of the well-knonw "Aeolian Harp" and is one of the reasons for the fluttering of a flag in a breeze.

In a somewhat similar manner, vortices tend to be formed at regular intervals and alternately behind the sides of a parallel-sided slit or orifice through which a blade-shaped sheet of fluid is caused to issue into a space containing the same fluid substantially at rest, and as before the frequency at which these vortices are formed alternately behind either edge of the slit tends to be proportional to the velocity of the issuing fluid and inversely proportional to the width of the slit, but to depend substantially upon no other factor or parameter provided again that the Reynold's number for the slit lies between certain limits. In practice, the vortices formed in this way tend to be weak and unstable in comparison with those formed at the sides of an obstacle and in certain applications of this phenomenon, for example in organ-pipes, a wedge of small angle is located behind the slit at a certain distance therefrom and parallel thereto in order to stimulate production of vortices at a desired frequency.

It has been proposed hitherto to utilize the phenomenon of alternate vortex-formation in two rows behind an obstacle as hereinbefore described in an arrangement for measuring the relative velocity between a

body and a contiguous fluid comprising a cylindrical member pivoted to the body about an axis perpendicular to the longitudinal axis of said cylindrical member and at one of the ends thereof, said axis of pivoting being parallel to the direction of flow of the fluid. Flow of fluid past such a member causes the formation, in the manner already explained, of two nearly-parallel rows of alternate and equally-spaced vortices, one row forming on each side of the member, and the breaking-away of these vortices alternately from opposite sides of the member imparts an alternating transverse force thereto. As a result, an alternating moment or couple is generated about the axis of pivoting of the member, the frequency of alternation of said moment or couple being substantially independent of the density and temperature of the fluid but proportional to its relative velocity. The cylindrical member is accordingly set into oscillation about the said axis of pivoting at the same frequency as that of the said moment or couple and this frequency is measured by suitable means and the relative velocity of the fluid thereby determined.

This proposed arrangement is, however, a disadvantageous one in that the vortices generated are only in contact with, and can exert substantial pressure on, said cylindrical member for a relatively short period during a cycle, so that the impulses given to the member by the alternating moments or couples are correspondingly small. With a typical cylinder, for example, the diameter of the vortices may be approximately of the same order of size as the radius of the cylinder whereas the distance between successive vortices in the same row may be of the order of eight times the said radius. At the same time, the moment of inertia of a cylindrical member oscillating about an axis perpendicular to its length and located at one of its ends is a maximum for any axis passing through the member so that the angle through which the said member is deflected by the impulses tends to be undesirably small. This disadvantage is made greater by the fact that on any body, such as a ship or aircraft, which is liable to be subjected to local vibration, the cylindrical member would have to be balanced by an equivalent mass positioned on the other side of the said axis from said member, thereby further increasing the moment of inertia of the member and decreasing the general sensitivity.

Furthermore, with the arrangement described considerable errors in the ultimate indications may arise if the direction of the flow of fluid past the cylindrical member is not accurately parallel with the axis of pivoting about which the said member oscillates, and such parallelism is not easy to ensure in many applications. This disadvantage exists even if the whole arrangement be mounted on a turn-table so as to permit rotation about the longitudinal axis of the cylinder in its mean position since it is not inherently self-aligning to the direction of flow of the fluid and extraneous means would have to be provided in order to effect such alignment, particularly if the device were utilized as an anemometer or the like.

It is a further object of this invention therefore to reduce or eliminate the above-mentioned disadvantages and to utilize the phenomenon of alternate vortex-formation in two rows behind an obstacle or orifice for the measurement and/or integration of fluid-velocities in a different and more efficient manner.

According to the invention there is provided a device for measuring and/or integrating the relative velocity between a body and a contiguous fluid, said device comprising a vane-like element immersed in the fluid and mounted on the said body, or on a part fixed relatively thereto, so that the plane of said element lies substantially along the direction of flow of the fluid past the body and so that the element is capable of oscillatory motion about a longitudinal axis substantially at right-angles to the direction of flow of the fluid, means such as an obstacle or orifice for generating a double system of travelling vortices in the fluid in such a way as to cause them to impart an alternating moment or couple to the element about said axis and cause it to oscillate with a frequency substantially proportional to the relative velocity between the fluid and body but independent of the density of the fluid, and means for measuring and/or integrating said frequency and translating it into a reading on an instrument calibrated to indicate the relative velocity of the fluid and/or the total flow of the fluid past the body in a specified time.

If desired means may be provided for automatically orientating the said vane-like element along the direction of flow of the fluid when this direction changes with regard to the body and also, if desired, means may be provided for measuring the orientation of the element relative to the body.

In one arrangement, the said vane-like element is combined with the obstacle in a single member and the obstacle is conveniently in the form of a cylindrical rod or tube having a projection or tail extending radially outwardly therefrom and longitudinally of said cylindrical rod or tube so as to form the oscillating element, the whole member being mounted for oscillatory motion about the longitudinal axis of the said rod or tube and arranged in the path of flow of the fluid with the said tail on the

downstream side of said cylindrical rod or tube and with the direction of the depth of said tail substantially parallel to the direction of flow of the fluid. If desired, the downstream half of the cylindrical rod or tube may be cut away to facilitate the production of vortices and the projection or tail tapered to the semi-diameter of the cut-away rod or tube. The said combined member may then be either journalled or pivoted in bearings fixed relative to the body, or alternatively be mounted so as to permit oscillation about a fixed shaft coaxial with the said longitudinal axis.

The flow of fluid past such a member causes the formation of a double system of vortices as hereinbefore described and the breaking away of these vortices alternately from opposite sides of the member imparts an alternating transverse moment or couple to the projection or tail of the element about the said longitudinal axis, which moment or couple will therefore cause said member to oscillate at the same frequency as the frequency of alternation of said moment or couple.

The length of the projection or tail is preferably made such that a vortex on one side of the projection or tail is just passing beyond the downstream end thereof as the succeeding vortex is being formed on the same side near the upstream end, whereupon each vortex acts on the projection or tail for substantially the whole of a cycle and will tend to produce a uniformly-increasing moment or couple about the longitudinal axis. The vortices on the other side of the projection or tail will correspondingly tend to produce a uniformly-increasing moment or couple about the longitudinal axis which is in the opposite sense and which is different in phase by a half-cycle, from which it can easily be shown that the net alternating moment or couple acting about the longitudinal axis tends to be constant in one direction for one half-cycle, and constant in the other direction for the other half-cycle, that is to say it has a wave-form which tends to be "square". The efficiency of such an arrangement is therefore high, and this fact, taken in conjunction with the fact that the moment of inertia of the member about its longitudinal axis is about the minimum for any axis passing through the member, ensures that the sensitivity of the arrangement is very much greater than in the case of the device previously described in connection with the prior art.

In a second arrangement, the double system of vortices is formed by a separate obstacle placed on the upstream side of the oscillating vane-like element, and the obstacle may be in the form of a plate at right-angles to the direction of flow of the fluid or, alternatively, be of cylindrical form with a cross-sectional shape similarly conducive to the formation of vortices. The cross-section, may, for example, take the form of a semi-ellipse with its bounding minor-axis perpendicular to the direction of the flow of the fluid at the downstream end and if desired the plane-face of the obstacle corresponding to the said minor-axis may have semi-cylindrical cavities or the like cut into it on either side of the centre-line so as to promote further the formation of vortices. With this arrangement the oscillating element may then take the form of a vane, preferably but not necessarily of symmetrical shape about its longitudinal axis of oscillation, said vane being suitably mounted so as to permit oscillation about said longitudinal axis, and said vane being located immediately behind the obstacle with its plane substantially in the extended centre-line of the obstacle and parallel to the direction of flow of the fluid. Vortices shed by the obstacle from either side or edge will then act on the vane in the manner hereinbefore described so as to impart an alternating moment or couple to it about its longitudinal axis and cause it to be set into oscillation.

As in the case of the previous arrangement it is preferred that the total length of the vane at right-angles to its longitudinal axis should be such that a vortex on one side is just passing beyond the downstream edge thereof as the succeeding vortex on the same side is beginning to overlap the upstream edge, since in this case each vortex is caused to generate a moment or couple on the vane about its longitudinal axis which tends, if the vane is symmetrical about said axis, to start at a maximum in one sense or direction, to decrease steadily to zero as it passes the longitudinal axis, and then to increase to a similar maximum in the other sense or direction. The vortices on the other side of the vane will correspondingly tend to generate a moment or couple of similar magnitude and form which is, however, of opposite sense and different in phase by half a cycle, from which it can easily be shown that, as in the case of the previous arrangement of this invention, the resultant alternating moment or couple about the longitudinal axis has a wave-form which tends to be "square". Taking into account, therefore, the fact that a vane or the type just described, especially if symmetrical about the axis of oscillation, may be very light and of small moment of inertia, it is clear that this arrangement of the present invention may be of even greater sensitivity than the one previously described.

In a third arrangement, an orifice is used to produce the double system or vortices,

and such an orifice may conveniently take the form of a parallel-sided slit located in the nose or upstream end of a suitable casing immersed in the fluid, said slit having the direction of its length perpendicular to the normal direction of flow of the fluid relative to the body. The said casing may be either an already-existing part of the body, for example the fuselage or a wing of an aircraft in the particular case when the arrangement is being used as an air-speed and/or air-distance indicator, or alternatively the said casing may be a special part attached to the said body and immersed in the fluid, in which case it is preferably of a cylindrical form having its longitudinal axis substantially at right-angles to the direction of flow of the fluid and having a streamline shape in cross-section, said casing being then so positioned that its axis of symmetry in cross-section is substantially parallel to the direction of flow of the fluid relative to the body. In all cases it is designed that the existence of the parallel-sided slit shall produce a blade-shaped sheet of fluid which flows through said slit at a velocity equal or proportional to the velocity of the fluid relative to the body, and which enters the casing and generates therein a double system of vortices behind the edges of the slit in the manner hereinbefore described, after which the said sheet of fluid is permitted to escape from the casing through suitable vents located in its downstream end.

The double system of vortices formed behind the edges of the parallel-sided slit in this way is then utilised as in the previous arrangements to cause a vane-like element positioned behind and slit on the downstream side, with its plane substantially parallel to the direction of flow of the sheet of fluid issuing therefrom, to oscillate about a longitudinal axis with a frequency substantially proportional to the velocity of the sheet of fluid and independent of its density, said axis being parallel to the sides of the slit and symmetrically located with respect thereto.

In one form of this arrangement the said longitudinal axis may be located at approximately one-fifth of the distance from the upstream edge of the vane to its downstream edge, so that the dynamic centre of pressure on the said vane is always on the downstream side of the longitudinal axis and the said vane is self-aligning to any small deviations in the direction of flow of the sheet of fluid issuing from the orifice. The vane may then be located so that its upstream edge is approximately in the plane of, or immediately behind the plane of, the downstream edges of the slit in the casing.

If desired, the production of vortices behind the downstream edges of the slit may be facilitated by bevelling the sides of the slit on their upstream faces and if desired also a wedge of small angle may be located for the same purpose inside the casing with its fine edge parallel to the slit and symmetrical thereto. In the latter case, the oscillating element may then be located on the downstream side of the said wedge and along its extended centre-line, and may be of symmetrical shape about its longitudinal axis of oscillation.

In all forms of this third arrangement is it preferred that, as in the case of the previous arrangements, and for the reasons hereinbefore stated, the length of the oscillating element at right-angles to its longitudinal axis should be such that a vortex on one side is just passing beyond the downstream edge thereof as the succeeding vortex on the same side is beginning to overlap the upstream edge.

In all the arrangements of the invention hereinbefore described it is preferred that the oscillating element, together with any other attachments on the spindle or the like constituting the longitudinal axis thereof (hereinafter called the complete oscillating element), should be balanced as far as possible in every plane at right-angles to the said axis, such balancing being desirable in order that the said complete element should not be forced into spurious oscillation by any vibration of the body upon which it is mounted. Immunity from such spurious oscillation is obviously of particular importance when the said body is a ship or aircraft, and may be preferably effected by suitable shaping of the complete element and/or addition to the complete element of suitably-positioned masses in each of the said planes, but if such a procedure be impracticable discrete masses may be rigidly attached to the said spindle or the like at suitably chosen points, so that the complete element is not only balanced statically but also dynamically. Preferably also the complete element, with or without said discrete masses, is so constituted that its moments of inertia about any two axes through the centre of gravity of said complete element at right-angles to one another and to the longitudinal axis are the same.

In all the arrangements hereinbefore described, it is also preferred that there should be provided sufficient elastic or resilient control of the complete element to ensure that the said element is dynamically stable and that the vane is maintained substantially in its correct alignment along the direction of flow of the fluid relative to the body despite the action of non-periodic and random moments or couples which may arise from temporary variations in the said

direction of flow of the fluid or from like causes.

The means whereby elastic or resilient control may be exerted on the complete element may comprise any known device such as springs or suitably-placed strips of rubber-like material, and, in the particular cases when the vane is immediately on the downstream side of a separate obstacle or of a wedge behind an orifice, a part or whole of the said control may be provided by making the upstream edge of the vane V-shaped and arranging for this edge to engage in a corresponding V-shaped slot on the downstream side of the separate obstacle or wedge, said slot being lined with a suitable strip of rubber-like material.

Alternatively, and particularly in cases where the frequencies of oscillation of the complete element, corresponding to the range over which it is desired to measure relative velocities between the body and the fluid, are all high it may be preferred to exert elastic control by means of the torsion of one or more thin rods, tubes, or ligaments forming a coaxial extension of the spindle or the like of the said complete element and fixed at the outer end or ends to a suitable point or points on the body, or on a part thereof. As a further alternative efficient elastic control may under similar circumstances be exerted by means of pairs of taut fibres or ligaments arranged in parallel with one another in a manner similar to that used for the well-known "bi-filar suspension", the component fibres or ligaments of each pair being normally parallel to, and equidistant from, the longitudinal axis of the complete element and being attached at one end to the said element and at the other end to a suitable fixed point on the body, or on a part thereof.

In many applications of the invention, especially in cases when the fluid is a liquid, it may be desirable to isolate or seal-off the vane or oscillating element from the other attachments on its spindle or the like, especially those attachments which are associated with the means provided for measuring and/or integrating the frequency of oscillation of the element. Such isolation or sealing-off is particularly desirable in, for example, ship's logs and flow-meters for measuring the flow of a liquid or a gas in a pipe, and may be provided by one or more fluid-tight glands with elastic sealing members through which the spindle is caused to pass. The said elastic sealing members may be, for example, annular rings or rubber or like substance which are forced under pressure into intimate contact with the said spindle, or may alternatively be in the form of tubular sleeves of rubber or like substance bonded internally to the spindle and externally to the body or a part thereof. Conveniently with such an arrangement elastic or resilient control of the oscillating element may then be provided, in whole or in part, by the said elastic sealing members, and, in the case where annular rings of rubber or the like substance are used, adjustment within certain limits of the magnitude of the control may be effected *in situ* by corresponding adjustment of the pressures on the said annular rings. In both cases, of course, the elastic control of the oscillating element may be arranged to have a predetermined value within certain limits by suitable choice of the "Shore Hardness" or elasticity of the rubber or like substance used to form the sealing members.

In all the arrangements hereinbefore described it is preferred that the elastic or resilient control of the complete element and also the total moment of inertia of the complete element about its longitudinal axis, should be as small as possible consistent with dynamic stability, since, under these conditions, the alternating moment or couple on the vane, due to the passage of the vortices, has for the most part only to overcome the damping moment or couple on the vane due to its resulting oscillation. It can be shown that in most applications of the invention both the above-mentioned moments or couples tend to be proportional to the density of the fluid and to the square of its velocity relative to the body and therefore the amplitude of oscillation of the vane, and thus its sensitivity, tends to be constant and independent of both the density and relative velocity of the fluid, whilst the change of displacement of the vane from one side to the other during a half-cycle of oscillation takes place with substantially uniform angular velocity, that is to say the displacement has a wave-form which is nearly "triangular". The characteristic in particular of constant sensitivity is obviously very advantageous, especially in applications of the invention where the fluid is a gas such as air, and where its density may vary widely, as is often the case during the flight of an aircraft.

The means for measuring and/or integrating the frequency of oscillation of the complete element and for translating it into a reading on an instrument calibrated to indicate the relative velocity between the fluid and the body and/or the total flow of the fluid past the body in a specified time, may comprise any known method for measuring the frequency of a mechanical vibration, such as a plurality of calibrated and tuned reeds, and any known method for integrating the frequency of a mechanical vibration such as the use of a mechanical counter or register, but will conveniently comprise electrical means for detecting the mechanical oscillation of the said element

and generating from such oscillation an alternating electrical voltage or current of the same frequency, which frequency can then be measured and/or integrated by any known method.

The means for detecting the mechanical vibration and for generating from such oscillation an alternating electrical voltage or current of the same frequency may comprise any known type of electrical transducer or vibration pick-up such as is used, for example, in gramophones or in devices for measuring the vibration of machinery or structures such as aircraft. Thus the said transducer or pick-up may be, for example, of either the moving-coil or moving-iron type, depending on the particular application of the invention, or on the other hand one of the well-known resistance types acting on the same principle as, for example, the carbon microphone or the resistance strain-gauge. Alternatively, the said transducer or pick-up may be of the capacitance type acting on the same principle as the so-called condenser microphone, or may utilise either the piezo-electric effect, as in the crystal microphone, or else the magneto-striction effect. In all cases it is preferred that the said transducer or pick-up shall be responsive primarily to rate-of-change of displacement rather than to displacement *per se* of the oscillating element, so that the ultimate readings are not substantially effected by non-periodic and random displacements of the element from its normal position of equilibrium.

One type of electrical transducer or pick-up, suitable for many applications of the invention, comprises an armature in the form of an I-shape block of laminations of magnetic material, said armature being rigidly attached to the spindle for oscillation with the complete oscillating element and so as to form with the latter a cross having symmetrical arms. The said armature in its normal position of equilibrium rests symmetrically between the limbs of two fixed and oppositely-facing U-shaped blocks of laminations of magnetic material and of identical construction, so that two pairs of equal air-gaps are created, one pair at each end of the armature with the corresponding air-gaps of each pair at opposite sides of the relevant end of the armature. A magnetic potential from, for example, a permanent magnet is applied to the two U-shaped blocks in series, thereby causing substantially equal magnetic fluxes to stream in parallel across each of the two pairs of air-gaps and forming in effect a magnetic analogy of the well-known "Wheatstone Bridge". Thus as a result of the equality of the air-gaps and consequent equality of their magnetic reluctance when the armature is in its normal position of equilibrium, no magnetic flux flows in either direction along the armature when in the said position of equilibrium but, when the said armature oscillates with the oscillating element, the balance of what may be called the "Magnetic Wheatstone Bridge" is upset first in one direction and then in the other, and an alternating magnetic flux is accordingly caused to flow in the armature at the same frequency as that of the mechanical oscillation. This alternating magnetic flux is in turn caused to generate an alternating electrical voltage in a suitable fixed coil linked with the armature.

The alternating electrical voltage or current generated by the mechanical oscillations of the complete element in a suitable electrical transducer or vibration pick-up such as that just described may then be amplified, if required, by known means and the frequency of the resulting electrical voltage or current output thereafter measured directly by a frequency-meter of known form such as, for example, is shown in my British Patents Nos. 384,703 and 422,202, said frequency meter being suitably calibrated to indicate the relative velocity between the body and fluid. At the same time, the said frequency may be integrated, if desired, to give a measure of the total fluid flow in a specified time by applying the said alternating electrical voltage or current output to a self-starting synchronous a.c. electrical motor, such as that generally known as a "self-starting phonic-wheel", the revolutions of which in a specified time may be counted by any known form of mechanical counter calibrated in terms of fluid flow or, in the case of logs or distance indicators, the distance traversed by the body through the fluid.

Alternatively, the electrical voltage or current generated in a suitable electrical transducer or vibration pick-up may, if required, be amplified and the resulting output limited in amplitude and converted by known electronic or magnetic means into an alternating electrical voltage or current, or in some cases an alternating magnetic flux, the wave-form of which is substantially "trapezoidal" and of constant amplitude at all frequencies. The said alternating voltage, current, or magnetic flux may then be differentiated, by known electronic or magnetic means, so as to produce discrete pulses of voltage or current of alternate sign, the number of said pulses of one sign per second being, of course, the same as the original frequency of the mechanical oscillations of the complete element. Voltage pulses produced in this way tend to have a peak value of voltage which is proportional to frequency, but their form is such that when applied to a circuit comprising resistance alone, or resistance and inductance

in series, the total quantity of electricity passed through the circuit as the result of each pulse is substantially constant and independent of frequency.

The said discrete pulses may then be rectified, if desired, and applied to any known circuit, electronic or otherwise which is adapted to the measurement of pulse-frequency, and as a result of which a reading may be caused to appear on an instrument calibrated in terms of the relative velocity between the body and the fluid. Examples of such circuits are the well-known Fitzgerald circuit and various adaptations of so-called "time-base" circuits using either hot-cathode or cold-cathode gaseous discharge-tubes, or alternatively hard valves.

One type of pulse-frequency measuring circuit which is especially convenient for logs in small ships which have no electrical supply, and which circuit may be described by way of example, comprises an electrical transducer or vibration pick-up of the "Magnetic Wheatstone Bridge" type as already described, the voltage output from which is applied to the primary coil of a saturable transformer, on which coil the number of turns is so related to the applied voltage that the core of the transformer is magnetically saturated each half-cycle. A secondary coil wound on the same core of the transformer as that on which the primary coil is wound is connected in series with a so-called "bridge-rectifier", the rectified output from which is then passed through a d.c. current-measuring instrument such as a moving-coil milliammeter. The changes of magnetic flux from saturation of the said core in one direction to saturation in the other direction accordingly produce discrete pulses of current of the type hereinbefore described, which pulses after rectification pass through the milliammeter in the same direction and develop therein an average current proportional to the frequency of oscillation of the oscillating element since the quantity of electricity in each pulse is substantially constant. The milliammeter may accordingly be calibrated in knots or as otherwise desired, final adjustment *in situ* of its readings to a correct value being effected by manipulation of a variable shunt in parallel with the coil of the instrument.

If required, known arrangements comprising, for example, an auxiliary coil on a suitable magnetic circuit in shunt may be incorporated in the said saturable transformer to compensate for any errors in the ultimate indications or readings on the milliammeter which may arise from incomplete saturation of the core of the said saturable transformer each half-cycle. Similarly any errors in the said ultimate indications or readings which may arise from alteration, due to temperature changes, of the ohmic resistances of the secondary coil of the saturable transformer; of "the bridge-rectifier", and of the coil of the milliammeter may be substantially eliminated by incorporating in the secondary circuit of the saturable transformer a suitably-placed resistor of appropriate value, said resistor being formed of a material such as certain semi-conductors which have a large and negative temperature-coefficient of resistivity.

The discrete pulses produced by any of the means hereinbefore described may also, or alternatively, be rectified if desired, and applied to any known circuit, electronic or otherwise, which is adapted to the counting of the total number of pulses generated in a specified time, and as a result of which a reading may be caused to appear on an instrument calibrated in terms of the total flow of the fluid past the body in the same time. Many examples of such circuits are known, and are employed, for example, in connection with research work in nuclear physics or in computing-devices.

If, for example, a circuit be used in which, as in the case of the pulse-frequency measuring circuit just described, a d.c. current is ultimately produced which is proportional to the said pulse-frequency, or in which d.c. voltage is ultimately produced which is proportional to the said pulse-frequency, the said current or voltage, or a derivative thereof, may be applied to a d.c. motor of the so-called integrating type having the property, like the well-known d.c. current-supply meter, that the number of revolutions developed per second is always proportional to the applied current or voltage, whereupon the total number of revolutions in a specified time, which may be determined by any known type of mechanical counter, is a measure of the total flow of fluid past the body in a specified time, or of the distance traversed by the body through the fluid. Alternatively, the total quantity of electricity passed in a given time when such a d.c. current varying proportionally to the pulse-frequency is produced, and which quantity is again a measure of the total flow of fluid, may be determined if desired by use of a suitable electrolytic-meter acting on the same principle as the meters of this type used in supply-systems.

If preferred, so-called triggered electronic counting-circuits may be used which may, for example, comprise a plurality of so-called "scale-of-two" counters of the well-known "flip-flop" type connected together in cascade, or a plurality of so-called "scale-of-ten" counters connected together in cascade, or any suitable combination of such counters arranged so as to actuate ultimately a mechanical counter or register suitably calibrated in terms of total fluid-flow.

Alternatively, or in addition, a plurality of so-called " transfer-tubes ", such as are, for example, known under the Registered Trade Mark " Dekatron ", may with their associated circuits be employed in cascade, and in such a case a mechanical counter or register may be omitted and the indications of total fluid-flow caused to appear on the " transfer-tube " themselves in the form of moving spots of light against appropriately-calibrated circular dials.

In one type of circuit particularly adapted to both the measurement and intgration of pulse-frequencies, and hence of fluid-velocities, in cases where it is desired to show the indications of both fluid-velocity and total fluid-flow on several " repeater " instruments, discrete voltage pulses of alternately opposite sign, and generated in the manner hereinbefore described, may be applied in so-called " push-pull " to the control-grids of two similar gaseous discharge-tubes of either the cold-cathode type or else of the hot-cathode type generally known under the Registered Trade Mark of " Thyratron ". The said pulses are applied through resistance-capacity networks so designed as to ensure that the amplitudes of the resulting positive voltage-pulses actually appearing on the said control-grids are substantially constant and independent of frequency, whilst the said control-grids are normally biased so that in the absence of said positive voltage-pulses the discharge-tubes are stable and quiescent, although the positive voltage pulses are of sufficinet magnitude in themselves to fire the discharge-tubes.

The cathodes of the discharge-tube are connected together in common to one side of a reservoir-capacitor and between the other side of the said reservoir-capacitor and the anode of each of the two discharge-tubes is connected an equal capacitor, the latter two capacitors each having a capacity very much smaller than that of the reservoir-capacitor. Each of the said equal capacitors (hereinafter called the discharge-capacitors) is connected at its end common with the anode of its respective discharge-tube through a similar anode-resistor to a stabilised source of High Tension voltage, the circuits therefrom being completed in such a way that a discharge-capacitor can be charged through its associated anode-resistor to very nearly the full value of the stabilised High Tension voltage when its associated discharge-tube, which is effectively in parallel with it, is quiescent.

The time-constant of each of the circuits comprising an anode-resistor and its associated discharge-capacitor in series with it is made such that the said discharge-capacitor can become substantially fully charged in the interval between the occurrence of two consecutive positive pulses of the same sign even at the highest designed pulse-frequency, but the application of such a positive pulse to the control-grid of its associated discharge-tube fires the latter and permits the discharge-capacitor to discharge very rapidly into the reservoir-capacitor until the voltage of the discharge-capacitor falls to the same valve as that of the said reservoir capacitor plus the small and substantially constant anode-to-cathode voltage drop in the discharge tube *per se* during discharge whereupon the discharge is extinguished. This process of transference of charge to the reservoir-capacitor is then repeated alternately by the two discharge-tubes in response to the discrete voltage-pulses as they are received.

The reservoir-capacitor has in parallel therewith a leakage-path comprising impedances so chosen in relation to the reservoir-capacitor that both the peak and average values of the resulting voltage appearing across the said reservoir-capacitor as the result of the above-mentioned process of repeated charge-tranference are small in comparison with the stabilised High Tension voltage, whence it follows that each of the discharge-capacitors is very nearly fully discharged when its associated discharge-tube fires and, having been originally charged to a constant voltage approximately equal to that of the stabilised High Tension supply, delivers a substantially constant quantity of electricity to the reservoir-capacitor on each such discharge. It therefore follows that under normal conditions the average current through the leakage path in parallel with the reservoir-capacitor, which of course equals the total quantity of electricity received per second by the said reservoir-capacitor, is substantially proportional to the original pulse-frequency, and hence to the fluid velocity.

The impedances in the leakage path across the reservoir-capacitor may comprise, in series with one another and a suitable inductor, one or more d.c. current-measuring instruments such as milliammeters, and also the field-coils of one or more d.c. motors of the integrating type, the armatures of which are supplied through appropriate resistors with constant d.c. current from a stabilised source of d.c. voltage. The magnetic circuit of the field of each of these motors has sufficiently large air-gaps therein to ensure that the field-flux is substantially proportional at all times to the field-current whence it follows that the torque developed in the motor is also proportional to the said field-current, since the armature-current is constant.

In view of the proportionality between the current in the said leakage-path and pulse-frequency, it is apparent that the milliam-

meters or equivalent instruments may be calibrated directly in terms of pulse-frequency, and hence of fluid-velocity. It is also arranged that the torque developed in each of the integrating motors is absorbed substantially completely in overcoming only the counter-torque developed by some form of brake such as the well-known "eddy-current brake", which brake is coupled mechanically to the armature of the integrating motor and in which brake the said counter-torque varies in proportion to the angular velocity of the armature. The said armature will therefore tend to rotate at all times at an angular velocity proportional to the fluid-current, and thus to pulse-frequency, so that the total number of revolutions of the armature in a specified time, which may be determined by any known type of mechanical counter or register, is a measure of the total flow fluid past the body in a specified time, or of the distance traversed by the body through the fluid.

The means whereby the oscillating vane-like element, which oscillates at a frequency proportional to the relative velocity between the body and the contiguous fluid, may if desired be caused to orientate itself automatically along the direction of flow of the said fluid, may make use of the fact that each of the arrangements of obstacle and oscillating-element hereinbefore described will, if permitted to do so, naturally tend to align itself along the direction of flow of the fluid by virtue of what may be called "weather-vane action".

In, for example, the arrangement first described in which the obstacle and oscillating element are combined in one common member such as a cylindrical rod with a longitudinal tail on the downstream side, the said common member together with its associated electrical transducer or vibration pick-up may be mounted on a rotatable turntable having a moment of inertia high compared with that of the said common member, so that the whole assembly will tend naturally to turn, by virtue of the said "weather-vane action", until the said tail is aligned along the direction of flow of the fluid, whilst the oscillations of the complete element, due to the flow of the fluid past it, will be superimposed upon this rotation. Due, however, to the very great difference between the moments of inertia of the complete element and the turntable, the response of the electrical transducer or vibration pick-up of the said turntable to the generally rapid oscillations of the combined member will not be appreciably affected by slow rotation of the turntable due to change of direction of flow of the fluid. The effect of rotation of the turntable will be smaller still if, as is preferred, the said electrical transducer or vibration pick-up is primarily responsive to rate-of-change of displacement and not to displacement *per se*.

In the case where the oscillating element is located behind a separate obstacle, the said obstacle with oscillating element and electrical transducer or vibration pick-up may again be mounted as a complete assembly on a rotatable turntable capable of rotation about an axis perpendicular thereto in the plane of the centre-line of the obstacle and suitably chosen so as to give maximum "weather-vane" action. Similarly, when the oscillating element is located behind an orifice in a streamline casing the said casing, with oscillating element and electrical transducer or vibration pick-up, may likewise be mounted as a complete assembly on a rotatable turntable capable of rotation about an axis perpendicular thereto in the plane of the centre-line of the casing and located at a point forward of the dynamic centre of pressure of the said casing.

In all the above-mentioned arrangements, suitable known damping means are preferably provided to ensure that unwanted oscillations of the turntable and its associated parts about the desired line of orientation are effectively suppressed, and slip-rings or the like are preferably provided for the purpose of taking off the alternating electrical voltages developed in the electrical transducer or vibration pick-up whilst permitting substantially free rotation of the turntable.

If desired also, the orientation of the turntable and its associated parts relative to the body, and hence the direction of the flow of the fluid relative to the body, may be communicated to a distance by making use of any known system for remote indication of angular position such, for example, as that generally known under the Registered Trade Mark "Selsyn", whilst the components of the velocity of the fluid relative to two chosen axes at right angles to one another in the body may be determined in any known way, such as by the use of so-called "sine-cosine resolvers" or suitably-wound potentiometers.

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SHEET 1

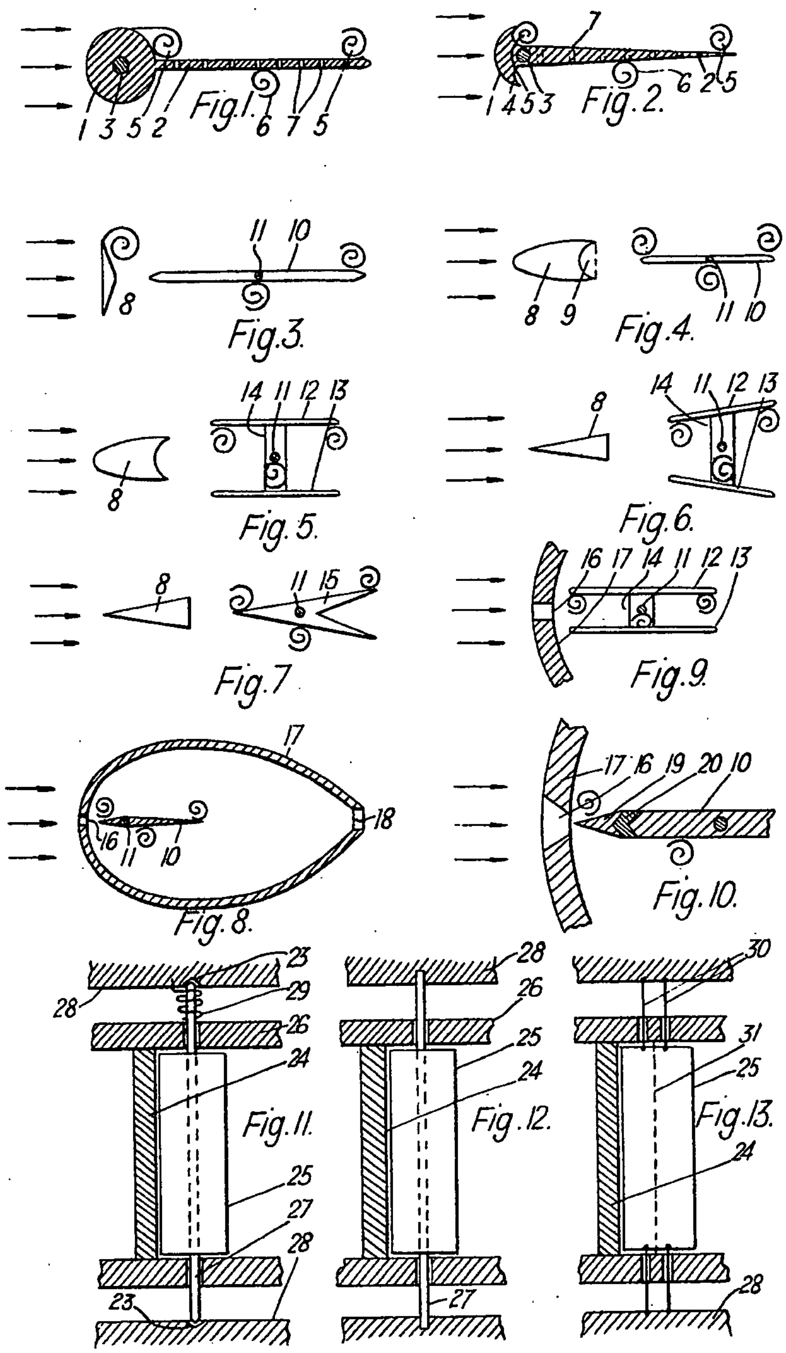


Fig. 14.

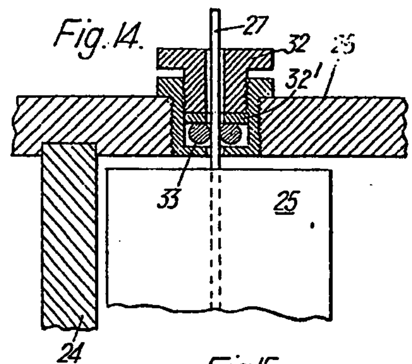


Fig. 15.

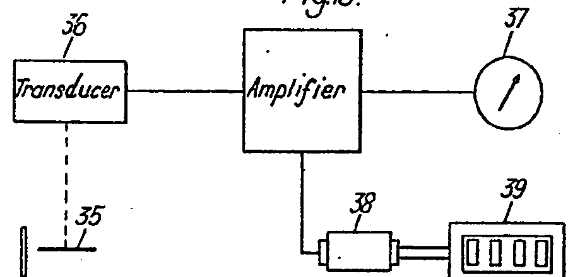


Fig. 16.

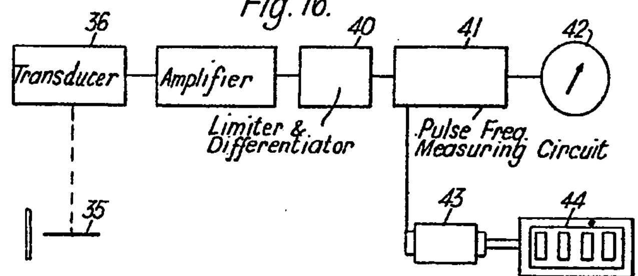
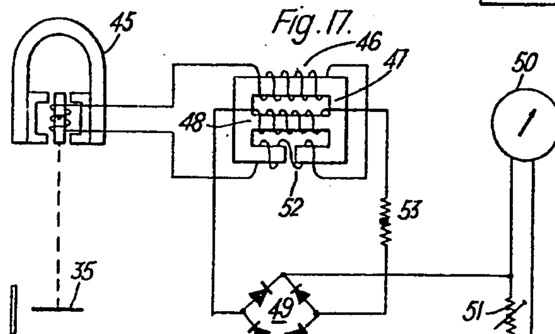


Fig. 17.



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3 SHEETS
This drawing is a reproduction of the Original on a reduced scale.
SHEETS 2 & 3

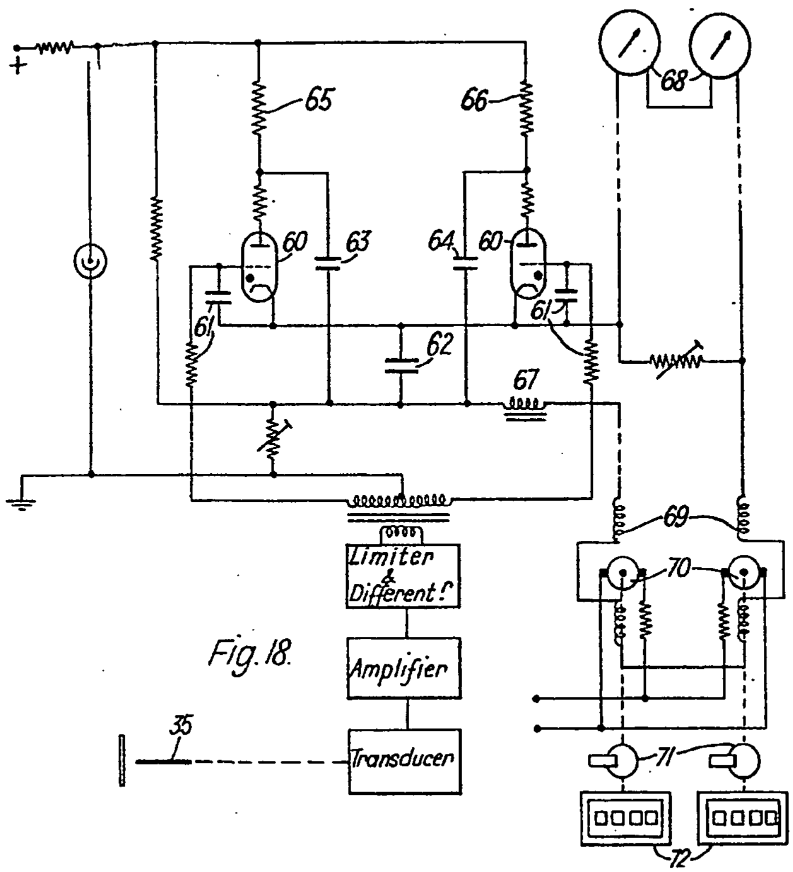


Fig. 18.

Fig. 19.

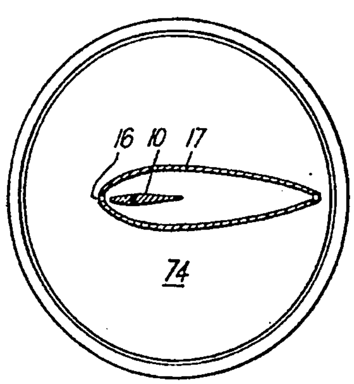
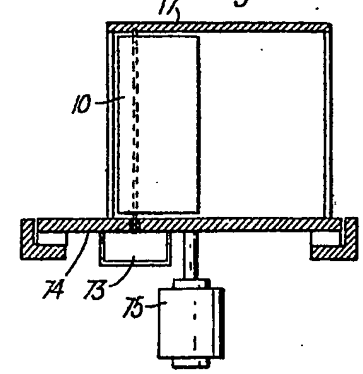


Fig. 20.



823,684 COMPLETE SPECIFICATION
3 SHEETS This drawing is a reproduction of the Original on a reduced scale.
SHEETS 2 & 3

Fig.14.

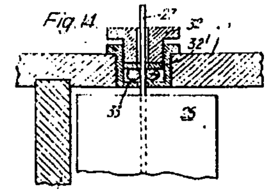


Fig.15.

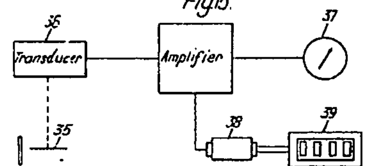


Fig 16.

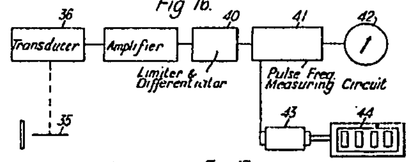


Fig.17.

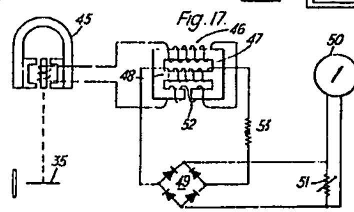


Fig.18

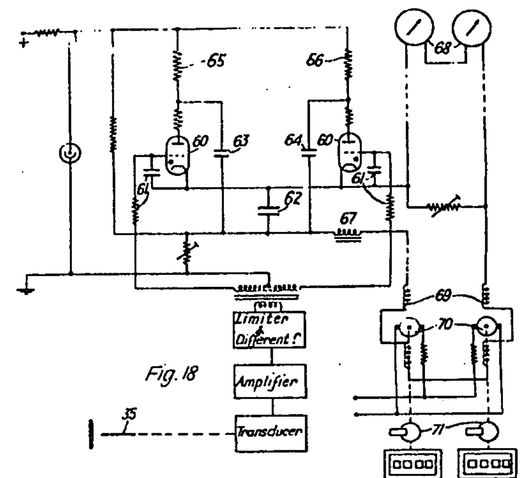


Fig.19.

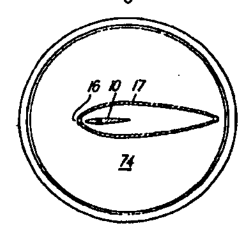


Fig.20.